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# Technical Report

Corrosion and Stress Corrosion of  
HY-130(T) Steel and HY-80 Steel  
in Marine Environments



Applied Research Laboratory  
United States Steel

Monroeville, Pennsylvania

July 15, 1967

Project No. 39.001-100(2)

CORROSION AND STRESS CORROSION OF HY-130(T)  
STEEL AND HY-80 STEEL IN MARINE ENVIRONMENTS  
39.001-100(2), a-ORD-NP-3

By A. W. Loginow

## Abstract

In two-year tests, the corrosion behavior of HY-130(T) steel plain-plate specimens was essentially equivalent to that of HY-80 steel. The HY-130(T) steel weldments, however, showed appreciably less corrosion than HY-80 steel weldments in these tests. In addition, the difference in corrosion rates between the various areas of the HY-130(T) steel weldment was appreciably less than for the HY-80 steel and is considered insignificant. In the marine atmosphere the corrosion rates after two years of exposure were relatively low and about the same for both steels. Both steels—plain-plate and welded HY-80 and HY-130(T)—were resistant to stress-corrosion cracking in the marine atmosphere and in sea water near the water surface. In the deep-sea tests, a delayed failure occurred in the weld metal of one of the HY-130(T) welded U-bend specimens.

Additional specimens are being tested in sea-water and marine atmospheres, and will be examined after four years of exposure.

### Introduction

For several years the Applied Research Laboratory (ARL) has been engaged in the development of a submarine-hull-steel weldment with a yield strength in the range 130 to 150 ksi. The corrosion and stress-corrosion behavior of candidate steels in marine environments was among the many properties determined during this development. Although submarine hulls are customarily protected from corrosion by the use of coating systems, such coatings deteriorate with time or they may be damaged, thereby leaving unprotected areas exposed to the corrosive action of sea water. Thus, the knowledge of the corrosion and stress-corrosion properties of steels intended for submarine-hull applications is considered an important aspect in the characterization of the steel.

The present report summarizes two-year corrosion and stress-corrosion results obtained on 5Ni-Cr-MO-V steel weldments, now designated HY-130(T), in surface waters and one-year results in deep-sea tests. The results of six-month and one-year surface-water corrosion tests have been reported earlier.<sup>1)\*</sup> The corrosion and stress-corrosion behavior of HY-80 steel, the current submarine-hull steel, was also determined for comparison purposes.

### Materials and Experimental Work

#### Corrosion Specimens

Corrosion specimens were prepared from two alloy steels — HY-80

\*See References

and HY-130(T) steel, Table I. All steels were heat-treated as shown in Table II before being fabricated into specimens. One group of specimens from each steel was without a weld (plain plate), whereas another group contained a weld.

The plain-plate specimens were cut to 4 by 12 inches from a 1/4-inch-thick plate of the HY-80 steel and from a 1/2-inch-thick plate of the HY-130(T) steel. Weldments were prepared from the steel plates by bevelling the edges of two plates (single V, 60 degrees), and depositing weld metal, Table I, in the V-groove. The HY-80 welds were made by using the shielded-metal-arc (SMA) process with E11018 covered electrodes. The HY-130(T) welds were made by using the gas-metal-arc (GMA) process. The weldment was then cut to 4- by 12-inch specimens so that the weld ran transverse to the specimen 6 inches from the ends. Next, all weldments were surface-ground to remove the reinforcement. Both the plain-plate specimens and the ground weldments were then gritblasted. After gritblasting, the specimens were weighed, measured, and mounted on racks as shown in Figures 1 and 2. All specimens were insulated from each other and from the test racks. The test racks were exposed to the marine environments described below.

The specimens used in deep-sea tests were prepared as described above except that the specimen dimensions were 6 by 12 inches. These specimens were mounted on Submersible Test Units (STU) designed and operated by the U. S. Naval Civil Engineering Laboratory (NCEL) at Port Hueneme,

California. Because of a misunderstanding, weight-loss data could not be obtained on these specimens.

#### Stress-Corrosion Specimens

U-bend stress-corrosion specimens were made from 1/2-inch-thick plate of the steels listed in Table I. The heat treatments and mechanical properties are given in Table II. Plain-plate stress-corrosion specimens were made from the plates by cutting 1- by 12-inch strips parallel to the rolling direction. Welded stress-corrosion specimens were made from 1/2-inch-thick plate by bevelling the edges of two plates (single V, 60 degrees) and depositing weld metal, Table I, in the V-groove by the SMA process (HY-80) or GMA process (HY-130(T)). The weldments were then surface-ground to remove the reinforcement. After the grinding, 1- by 12-inch strips were cut from the weldment in such a way that the weld ran transverse to the strip about 5 inches from one end. Both the plain-plate specimens and the ground weldments were then gritblasted.

The specimens were then stressed by bending them over a 2.5-inch-diameter mandrel until the specimen legs were parallel. A bolt was inserted through holes in the specimen ends, and a nut was tightened until all stress was borne by the bolt. This procedure stressed the outer fibers of the U-bend specimens well beyond the 0.2-percent offset yield strength. The nominal strain on the outer fibers was 16.5 percent. Figure 3 shows a stressed welded U-bend specimen. To prevent galvanic action between the

specimens and the stressing bolts, nuts, and washers. The specimen ends were coated with a neoprene system.<sup>2)</sup> The specimens were then exposed to the marine environments described below.

#### Exposure of Specimens in Surface Waters

Corrosion and stress-corrosion specimens were exposed to the following marine environments:

1. Sea water (total immersion in quiescent sea water).  
Specimens were suspended 1 to 2 feet below the water surface from a float at The International Nickel Company's Testing Station at Wrightsville Beach, North Carolina.
2. Sea water (tidal zone). Specimens were suspended from a dock at Wrightsville Beach below the high-tide line and above the low-tide line. Alternate wetting and drying occurred twice a day.
3. Sea water (flowing). Specimens were exposed at Wrightsville Beach in a trough with sea water flowing at about 2 feet per second.
4. Marine atmosphere. Specimens were exposed on atmospheric test racks in the 80-foot lot at Kure Beach, North Carolina.

Two specimens of each of the plain plate and welded corrosion

specimens of HY-80 Heat No. X51289 and HY-130(T) Heat No. X53185 were exposed to each of the above environments for evaluation after about 6 months, 1 and 2 years. At the end of the respective exposure periods, the specimens were removed from the environment, cleaned of marine growth, and returned to the ARL. The corrosion products were removed from the specimens by cleaning in a molten sodium hydride bath. The clean plain-plate specimens were then weighed, and their weight loss was determined and converted to thickness loss and corrosion rate. On weldments the corrosion rate was calculated from micrometer measurements of the thickness of the weld metal, the heat-affected zone, and the base metal.

Three plain-plate and three welded stress-corrosion specimens of HY-80 steel (Heat No. X51289) were exposed in each sea-water environment and two specimens of each kind were exposed in a marine atmosphere. In addition, three welded HY-80 steel (Heat No. 73L498) specimens were exposed in the marine atmosphere and totally immersed in sea water.

Three plain-plate and three welded HY-130(T) steel (Heat No. X53185) stress-corrosion specimens were exposed in each of the marine environments. In addition, three plain-plate, rapidly heat-treated HY-130(T) steel (Heat No. X53957) specimens were exposed in the tide zone and in the flowing-water environments, whereas two specimens were exposed in the marine atmosphere and totally immersed in sea water.

All stress-corrosion specimens were visually inspected for cracks.



The inspections were performed weekly during the first two months of exposure, every two weeks for the next two months, and monthly thereafter.

#### Exposure of Specimens in Deep-Sea Tests

In the deep-sea tests, duplicate plain-plate and welded corrosion specimens and triplicate stress-corrosion specimens of HY-130(T) (Heat No. X53185) were exposed in the Pacific Ocean. One set of specimens was exposed for about 6 months (197 days) at a nominal depth of 2500 feet, and another set for about 1 year (403 days) at a nominal depth of 6000 feet. Detailed exposure conditions obtained from NCEL are listed in the Appendix.

At the end of the respective exposure periods, the specimens were recovered from the ocean by NCEL and returned to the ARL for evaluation. Intermediate inspections were not performed. Because of a misunderstanding with NCEL, the initial weights of the specimens were not measured and hence corrosion rates could not be established. However, the specimens were examined visually and pit depths were measured.

#### Results and Discussion

##### HY-80 Steel

The results obtained from plain-plate HY-80 steel specimens are given in Figure 4. The corrosion rate of this steel decreased during the 2-year exposure in the tide zone, in flowing sea water, and in marine atmosphere. The initial corrosion rates of about 13 mils per year (mpy) in the

tide zone, about 11 mpy in flowing sea water, and about 2 mpy in the marine atmosphere decreased appreciably after about one year of exposure. During the second year of exposure the corrosion rates were about 0.7 mpy in the tide zone, 0.2 mpy in flowing sea water, and 0.3 mpy in the atmosphere. In the total-immersion exposure the corrosion rate remained essentially constant at about 3 mils per year. The gradually decreasing corrosion rates, in all exposure conditions except total immersion, indicate that the rust films were becoming protective.

The corrosion behavior of welded HY-80 steel specimens is given in Figures 5, 6, and 7 for the base metal, heat-affected zone, and weld-metal, respectively. In all sea-water environments the weldments were corroded most in the weld metal and in the base metal, and considerably less in the weld heat-affected zone. In the marine atmosphere the corrosion rates were approximately equal (1.0 to 1.5 mpy) in the three areas of the specimens and did not change appreciably during the two-year exposure period. In the sea-water environments the corrosion rates of base metal and weld metal were about 5 to 10 mpy for the first year of exposure but increased to about 30 to 50 mpy in the second year. In the heat-affected zone the corrosion rates remained essentially constant at about 5 to 10 mpy during the two-year exposure period. The increase in corrosion rate of the base metal is inconsistent with the corrosion behavior of plain-plate specimens. The cause of this anomaly has not been established, but this behavior is believed to be

related to the presence of a galvanic cell consisting of the base metal and weld metal as the anodes, and the heat-affected zone as the cathode. It is conceivable that marine fouling on the surface of the specimen prevented dilution of the acid anolyte which, in turn, caused the increase of corrosion rate. As will be shown later, the corrosion rates of HY-130(T) weldments did not increase with time. Furthermore, it was determined in an earlier ARL study<sup>3)</sup> that the various areas of the HY-130(T) steel weldments did not constitute a strong galvanic cell.

The results of stress-corrosion tests are summarized in Table III. In all environments tested the HY-80 steel U-bend stress-corrosion specimens of Heat No. X51289 did not show any cracks after 43 months of exposure, and those of Heat No. 73L498 showed no cracks after 37 months. The stress-corrosion tests are continuing.

#### HY-130(T) Steel in Surface Waters

The results obtained from plain-plate HY-130(T) steel specimens exposed in surface waters are given in Figure 8. The observed corrosion was very uniform on all surfaces of the specimens. The corrosion rates decreased during the two-year exposure, in total immersion, in the tide zone, and in the marine atmosphere. The initial corrosion rates were about 5 mpy in total immersion, 6 mpy in the tide zone, and 2 mpy in the atmosphere. After about one year the corrosion rates decreased, and during the second year of exposure they were about 1.5 mpy in total immersion, 0.7 mpy in the tide zone,

and 0.5 mpy in the atmosphere. In the flowing sea-water the corrosion rate remained essentially constant at about 7 mpy over the 2-year test period. The decreasing corrosion rates, in all exposure conditions except flowing sea-water, indicate that the rust films formed were gradually becoming protective. Considering the corrosion test as a whole, it can be concluded that the general corrosion behavior of plain-plate HY-130(T) steel specimens is substantially equivalent to the corrosion behavior of HY-80 steel.

The corrosion behavior of welded 5Ni-Cr-Mo-V steel specimens is given in Figures 9, 10, and 11 for the base metal, heat-affected zone, and weld metal, respectively. In flowing sea water and in the tide zone the welded HY-130(T) steel specimens corroded in the weld metal (4.0 - 9.0 mpy) somewhat more than in the base metal (1.5 - 6.7 mpy) or heat-affected zone (0.3 - 2.5 mpy). However, the difference in corrosion rates between the various areas of the weldment is not considered significant. This corrosion behavior is consistent with earlier laboratory tests<sup>3)</sup> which showed that the corrosion potentials of the weld metal were only 6 to 7 millivolts anodic to those of the base metal.

The corrosion rates of HY-130(T) steel base metal obtained from welded specimens were essentially identical with those obtained on plain-plate specimens. In general, these tests in various marine environments showed that HY-130(T) weldments were appreciably more corrosion resistant than HY-80 steel weldments.

The results of stress-corrosion tests are summarized in Table III. In all environments tested the HY-130(T) steel plain-plate and welded U-bend stress-corrosion specimens of Heat No. X53185 (heat-treated to 152 ksi yield strength) did not show any cracks after 37 months of exposure. Cracking was also not detected after 24 months of exposure in Heat No. X53957, which was heat-treated to 195 ksi yield strength and exposed only as plain-plate U-bend specimens. The stress-corrosion tests are continuing.

#### HY-130(T) Steel in Deep-Sea Tests

Examination of the HY-130(T) steel specimens showed only a moderate amount of general corrosion. Specimens exposed at 2500 feet were not pitted, and those exposed at 6000 feet had a few randomly distributed shallow pits (average - 2.7 mils/year; maximum - 8.1 mils/year). There was also no indication of galvanic attack between the base metal and the weld metal.

There were no cracks in the plain plate or welded HY-130(T) steel stress-corrosion specimens exposed at 2500 feet. At the 6000-foot depth, however, one welded specimen had cracked in the weld metal, Figure 12. The other welded specimens and the plain-plate specimens did not crack. As was discussed earlier, similar stress-corrosion specimens exposed in sea water near the surface at Wrightsville Beach, North Carolina, have not cracked in 37 months. Although the reason for the single incident of delayed cracking is not known, Figure 12 suggests that cracking may have initiated during bending of the specimen, as indicated by the initial 45-degree fracture. In

addition, the weld metal used is one of the early experimental materials, which subsequently was found to be susceptible to delayed cracking in the absence of corrosion environments.

#### Summary

Plain-plate and welded corrosion and stress-corrosion specimens of HY-80 steel and HY-130(T) steel were exposed to sea water in total immersion, in the tide zone, in a trough with flowing water, and in a marine atmosphere.

In two-year tests the corrosion behavior of HY-130(T) steel specimens was substantially equivalent to that of HY-80 steel. Weldments of HY-130(T) steel in two-year sea-water tests showed less corrosion than weldments of HY-80 steel, the current submarine-hull steel. In sea water the HY-80 steel weldments were corroded most in the weld metal and in the base metal, and considerably less in the heat-affected zone. For the HY-130(T) steel the difference in corrosion rates between the various areas of the weldment was appreciably less than for the HY-80 steel and is considered insignificant.

In the marine atmosphere the corrosion rates after two years of exposure were relatively low and about the same for both steels.

Both steels — plain-plate and welded HY-80 and HY-130(T) steels — were resistant to stress-corrosion cracking in marine atmosphere and in

shallow sea water. In the deep-sea tests, a delayed failure occurred in the weld metal of one of the HY-130(T) steel welded U-bend specimens. In addition, plain-plate and welded specimens exposed in the Pacific Ocean at 2500- and 6000-foot depths showed only a moderate amount of corrosion. In these deep-sea tests there was no indication of galvanic attack between base metal and weld metal.

#### Recommendations and Future Work

Additional corrosion specimens are presently being tested in sea water and atmospheric exposures; these specimens will be examined after a 4-year exposure. The exposure of stress-corrosion specimens is continuing; these specimens will be examined at regular intervals.

#### References

1. A. W. Loginow, "Corrosion of Experimental Submarine Hull Steels in Marine Environments," ARL Report 39.001-100(1), September 30, 1965.
2. A. W. Loginow, "Stress-Corrosion Behavior of 12 Percent Manganese Steel Weldments," ARL Report 40.001-100(3), December 31, 1964.
3. E. Williams, "Electrochemical Behavior of Experimental Submarine Hull Steels in Synthetic Sea Water," ARL Report 40.001-008(1), September 30, 1964.

## Appendix

### Exposure Conditions for the Deep-Sea Tests

	<u>2500-foot site</u>	<u>6000-foot site</u>
Location	34°06'N, 120°42'W	33°46'N, 120°46'W
Depth	2340 feet	6780 feet
Pressure	1040 psi	2983 psi
Salinity	34.4 parts per thousand	34.6 parts per thousand
Oxygen	0.42 ml/l (0.60 ppm)	1.19 ml/l (1.70 ppm)
Temperature	45 F	37 F
pH	7.46	7.25
Sediment	Firm, sandy, green cohesive mud	Firm, green mud and rocks
Current	About 0.3 knot	Less than 0.5 knot
Date exposed	June 3, 1964	June 10, 1964
Date retrieved	December 17, 1964	July 18, 1965
Exposure time	197 days	403 days

NOTE: These data were obtained from the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California.



Table I

Composition of Steels Used in Corrosion Tests  
(Check Analyses)

Steel	Heat No.	C	Mn	P	S	Si	Ni	Cr	Mo	V	Ti	Al	N
HY-80	X51289	0.13	0.29	0.009	0.011	0.25	2.97	1.60	0.51	0.01	ND	0.058	0.012
HY-80	73L498	0.16	0.31	0.012	0.019	0.22	2.27	1.36	0.31	0.01	0.006	0.042	0.005
HY-130 (T)	X53185	0.11	0.74	0.007	0.006	0.27	4.98	0.58	0.54	0.064	0.005	0.024	0.011
HY-130 (T)	X53957	0.10	0.76	0.004	0.004	0.22	5.0	0.52	0.54	0.054	ND	0.021	0.010
<u>Weld Metals*</u>													
For HY-80	ELL018**	0.06	1.54	0.022	0.019	0.35	1.78	0.32	0.44	0.022	0.009	0.007	ND
For HY-130 (T)	R9376-B	0.10	1.86	0.005	0.006	0.37	2.00	0.73	0.54	ND	0.016	ND	ND

ND - Not determined.

\* Composition of undiluted filler metal.

\*\* AWS designation.

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UNITED STATES STEEL

Table II  
Heat Treatment and Mechanical Properties of  
Steels Used in Corrosion Tests

Steel	Heat No.	Heat Treatment	Yield Strength (0.2% offset) ksi	Tensile Strength, ksi	Elongation in 2 inches, percent	Reduction of Area, percent
HY-80	X51289	1650 F, WQ*, 1250 F, WQ	90	105	38	68
HY-80	73L498	1660 F, WQ, 1350 F, WQ	90	106	25	78
HY-130(T)	X53185	1500 F, WQ, 1120 F, WQ	152	159	20	73
HY-130(T)	X53957	Rapid**	195	204	15	67

\* WQ - Water quench.

\*\* The steel was hardened in 5 passes, each consisting of heating at 200 F/sec to from 1400 F to 1430 F and quenching in a water spray to room temperature. The hardening procedure was followed by conventional tempering at 400 F for 1 hour.

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Table III

Results of Stress-Corrosion Tests

Environment	Time to Cracking, months					
	HY-80 steel			HY-130(T) steel		
	Heat X51289		Heat 73L498	Heat X53185		Heat X53957
	plain-plate	welded	welded	plain-plate	welded	plain-plate
Sea water - total immersion	NF43	NF43	NF37	NF37	NF37	NF24
Sea water - tide zone	NF43	NF43		NF37	NF37	NF24
Flowing sea water	NF43	NF43		NF37	NF37	NF24
Marine atmosphere	NF43	NF43	NF37	NF37	NF37	NF24

NF - No failure in the number of months indicated.

39.001-100(2)

UNITED STATES STEEL



Figure 1. Plain-plate specimens mounted on a rack for exposure in the tidal zone. Approximately 1/14 actual size.

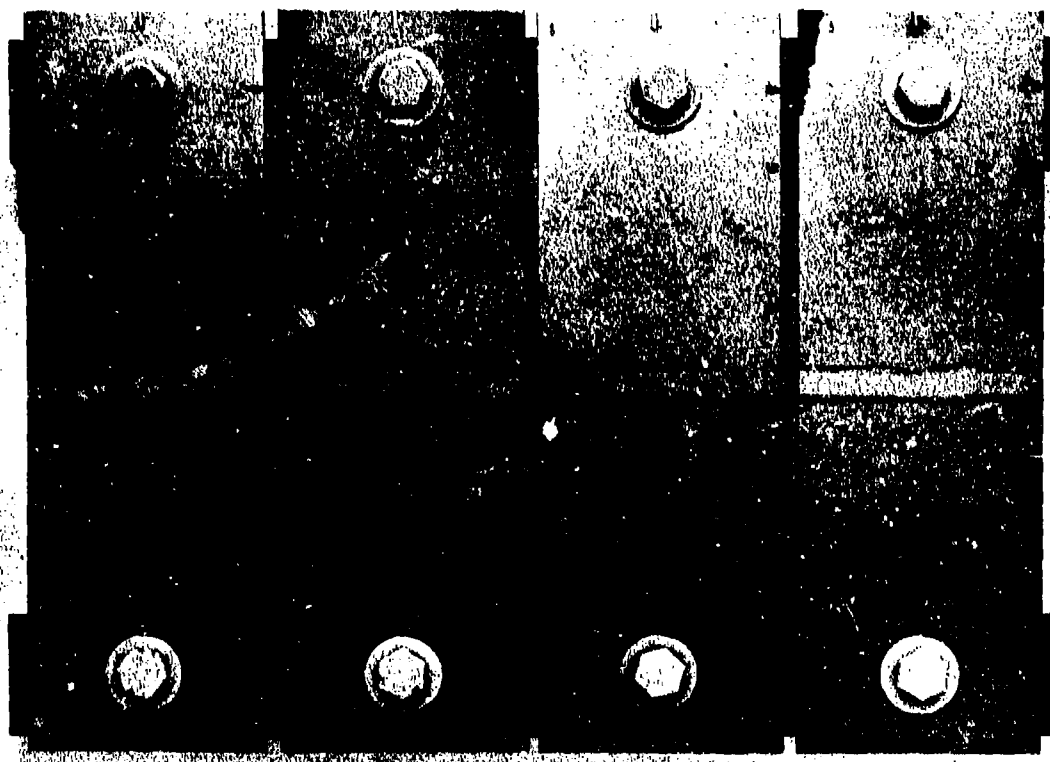


Figure 2. Welded specimens mounted on a rack for exposure in flowing sea water. Approximately 1/4 actual size.

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Figure 2

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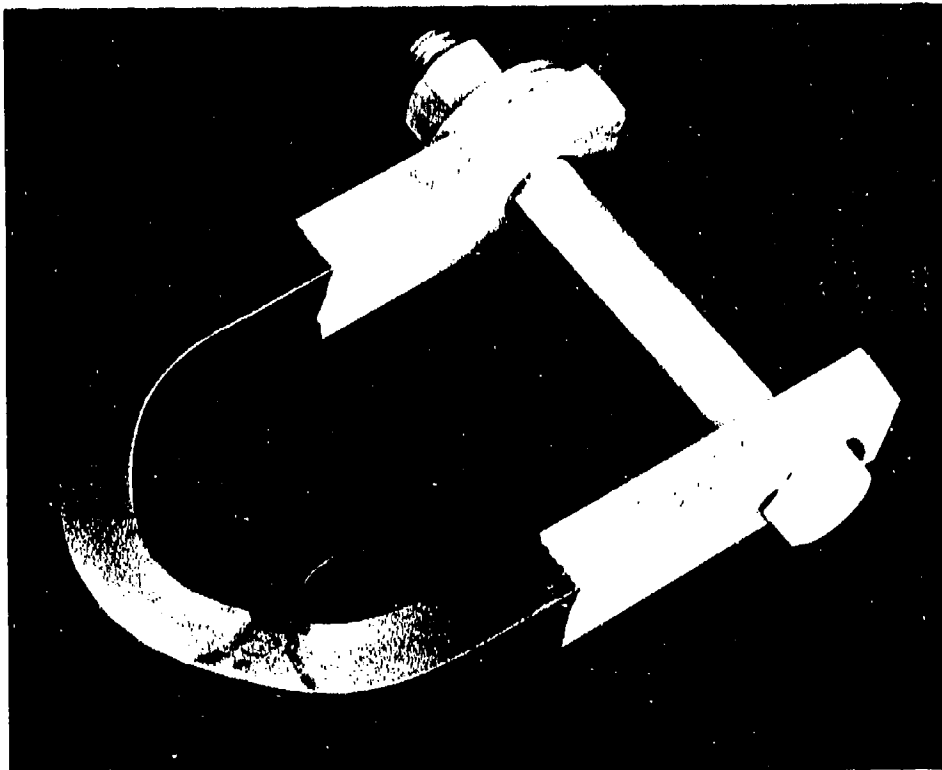
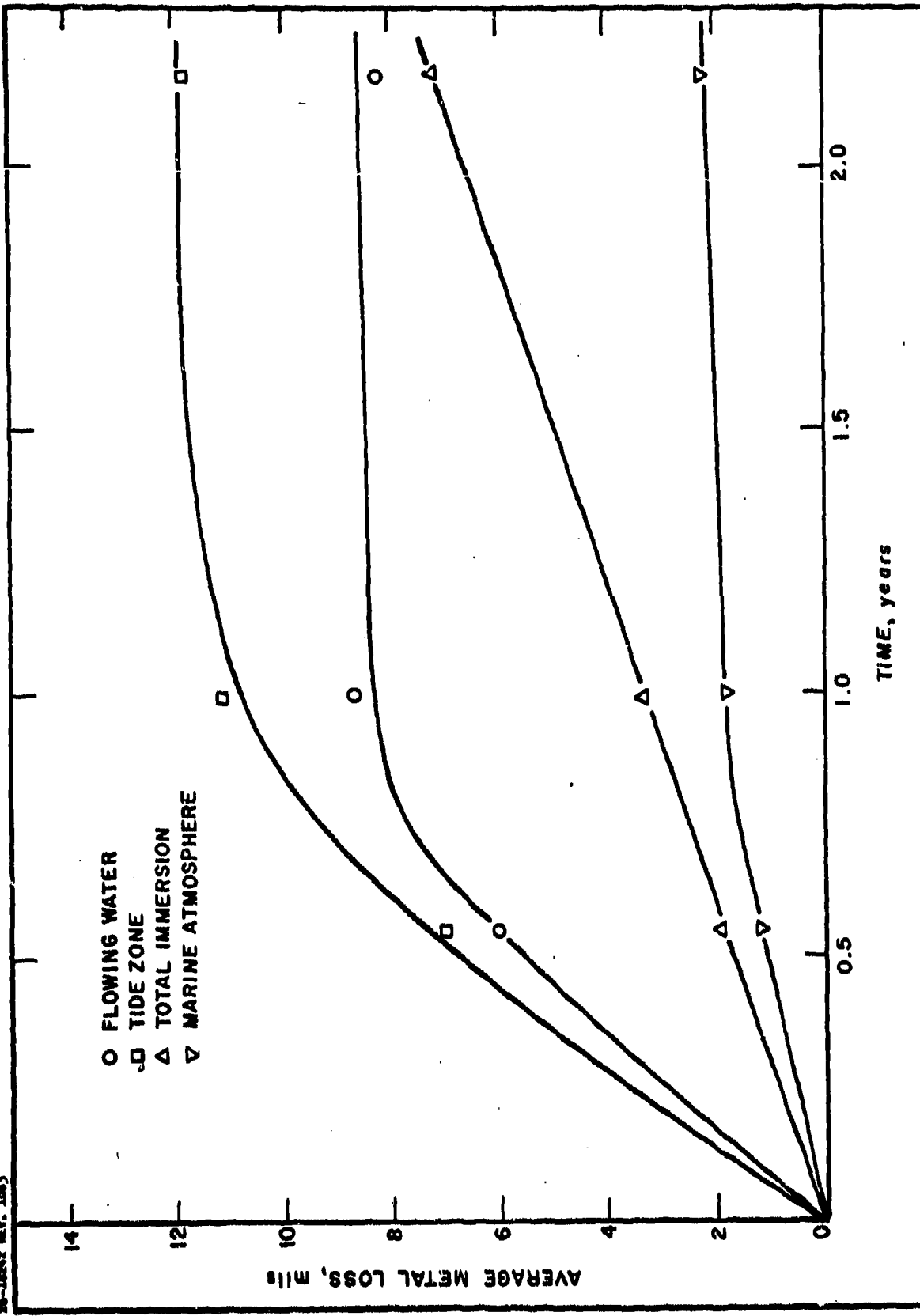
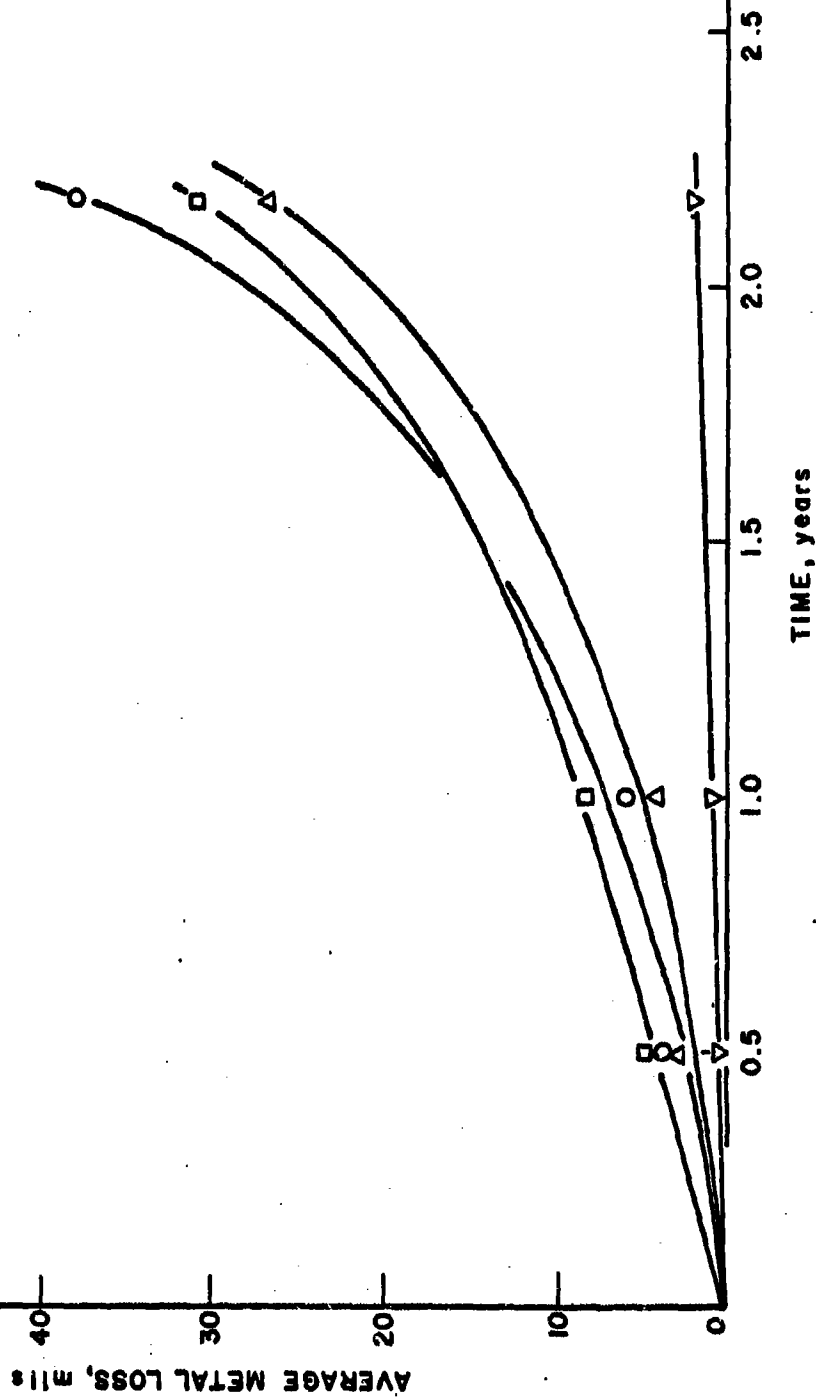


Figure 3. U-bend stress-corrosion specimen  
machined from welded plate.  
Approximately 1/2 actual size.



**CORROSION OF HY-80 STEEL IN MARINE ENVIRONMENTS**

DRAWN BY G.A.Z.		CHK'D BY A.W.L.	APPROVED BY E.H.P.	FIGURE NO. <b>4</b>
DRAWING NO <b>ARL 1-1444</b>		PROJECT NO 39.001-100 (2) DATE 6-12-67		
UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.				



# BASE-METAL CORROSION OF HY-80 STEEL WELDMENTS IN MARINE ENVIRONMENTS

DRAWN BY: CHK'D BY: APPROVED BY:  
G.A.Z. A.W.L. E.H.P.

**DRAWING NO.**

**PROJECT No.**

**39.001-100**

**6-12-67**

**FIGURE**  
**NO.**

**UNITED STATES STEEL CORPORATION**

## APPLIED RESEARCH

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- O FLOWING WATER
- TIDE ZONE
- △ TOTAL IMMERSION
- ▽ MARINE ATMOSPHERE

AVERAGE METAL LOSS, mils

TIME, years

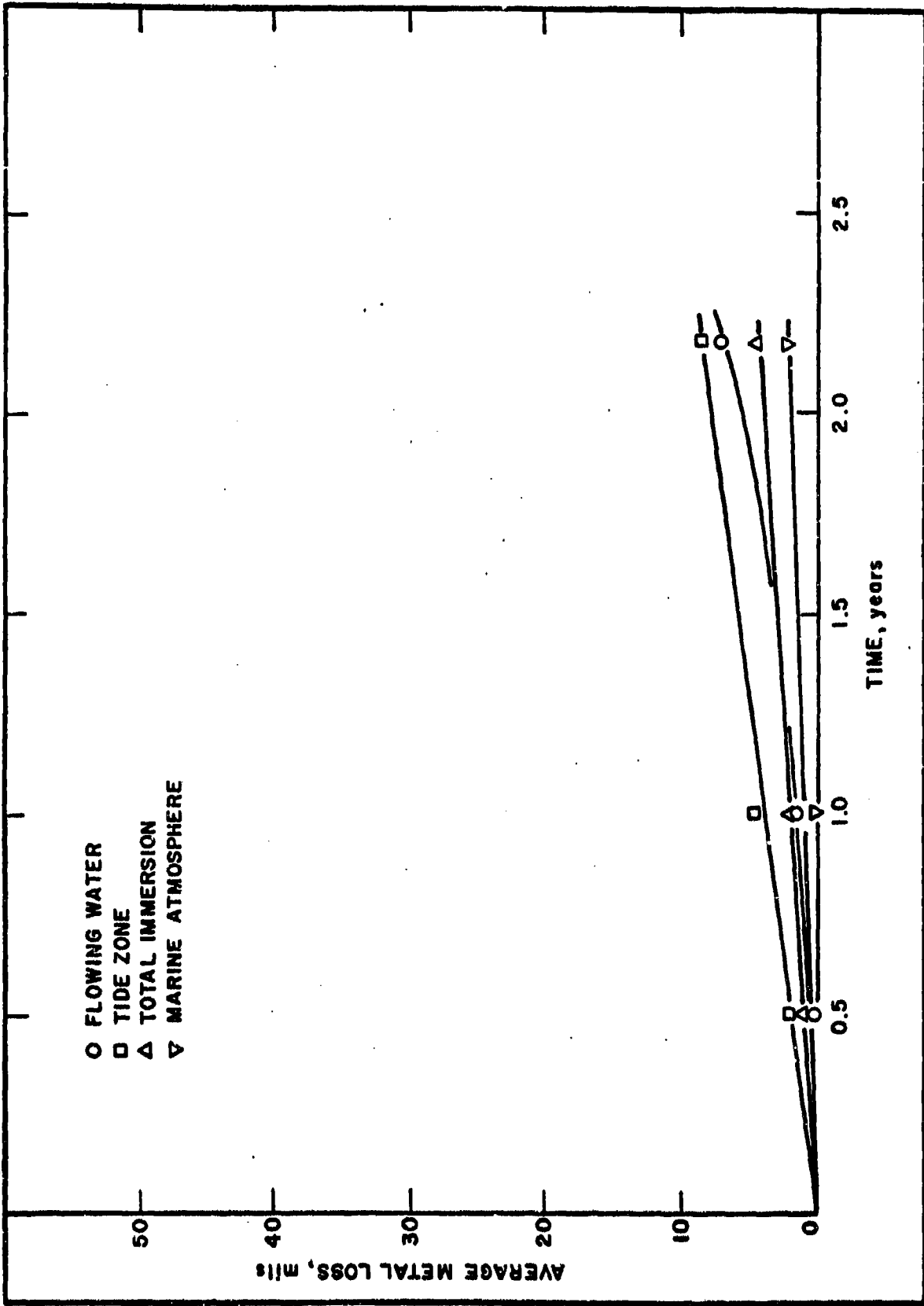
# HEAT-AFFECTED-ZONE CORROSION OF HY-80 STEEL WELDMENTS IN MARINE ENVIRONMENTS

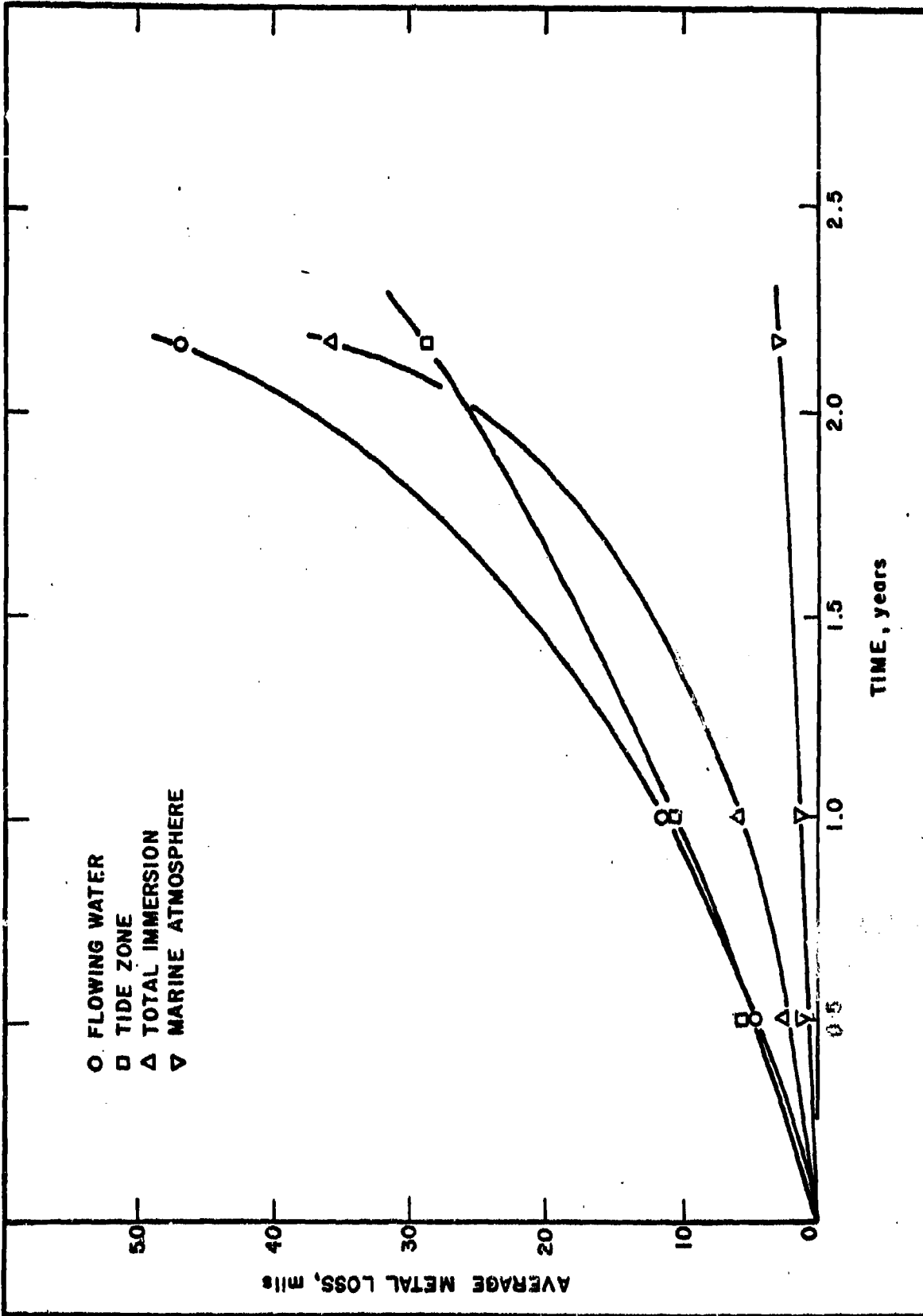
DRAWN BY CHK'D BY  
G. A. Z. A. W. L.  
DRAWING NO  
ARL 1-1446

APPROVED BY  
E. H. P.  
PROJECT NO  
39.001-100 (2)  
DATE  
6-12-67

UNITED STATES STEEL CORPORATION  
APPLIED RESEARCH  
PITTSBURGH, PA.

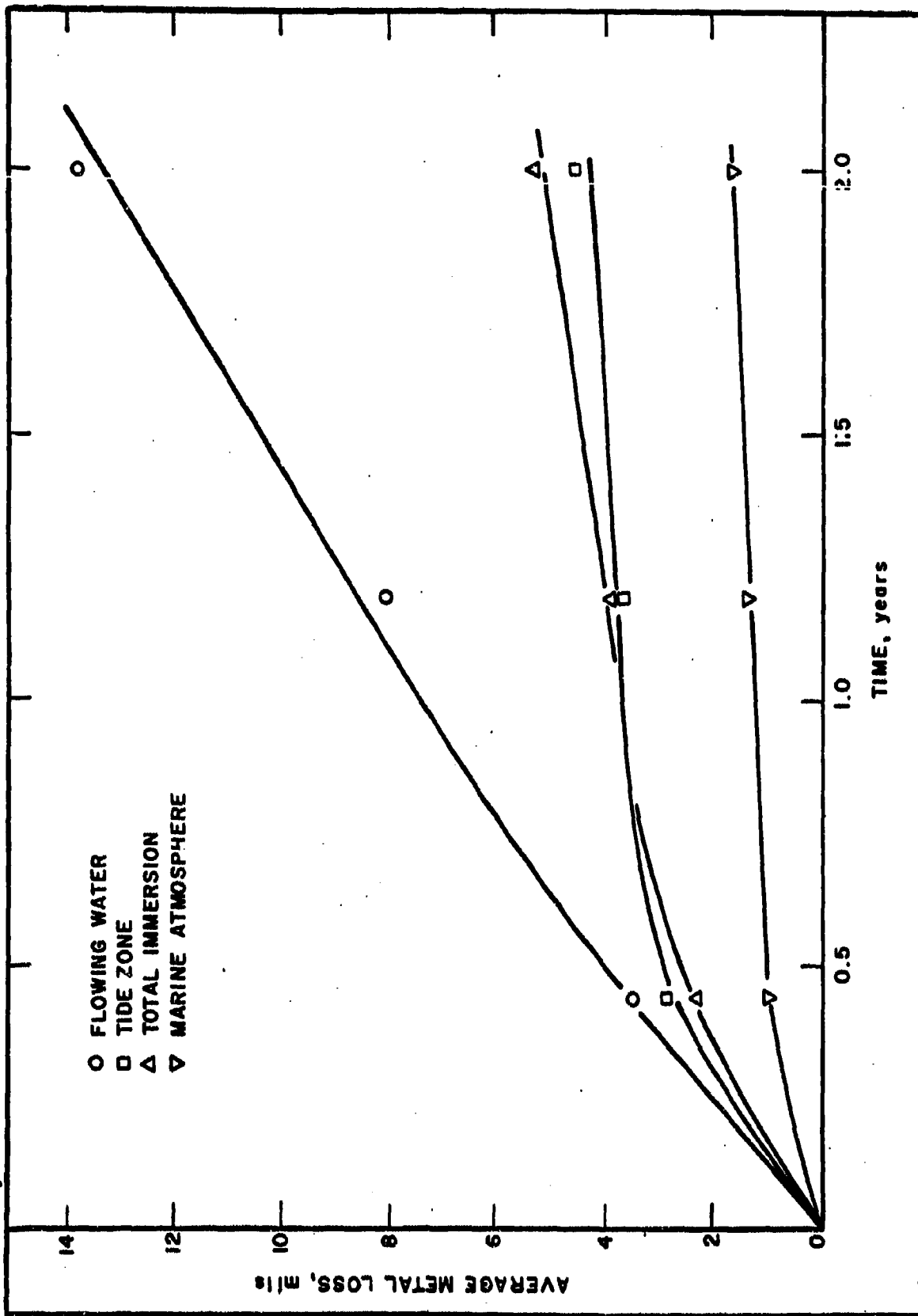
FIGURE  
NO.  
6





WELD-METAL CORROSION OF HY-80 STEEL WELDMENTS IN MARINE ENVIRONMENTS

DRAWN BY G. A. Z.		CHK'D BY A. W. L.	APPROVED BY E. H. P.	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 7	
DRAWING NO ARL 1-1447		PROJECT NO 39,001-100 (2)				
		DATE 6-12-67				

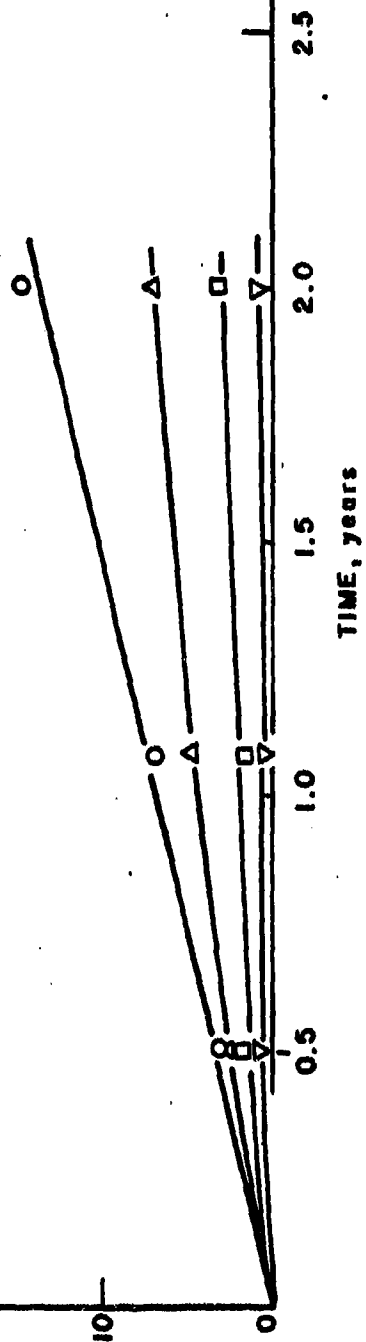


**CORROSION OF HY-130(T) STEEL IN MARINE ENVIRONMENTS**

DRAWN BY CHKD BY A. Z. A.W.L.		APPROVED BY E.H.P.	<b>FIGURE NO. 8</b>
DRAWING NO <b>ARL1-1448</b>		PROJECT NO <b>39.001-100(2)</b>	
		DATE <b>6-12-67</b>	UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.

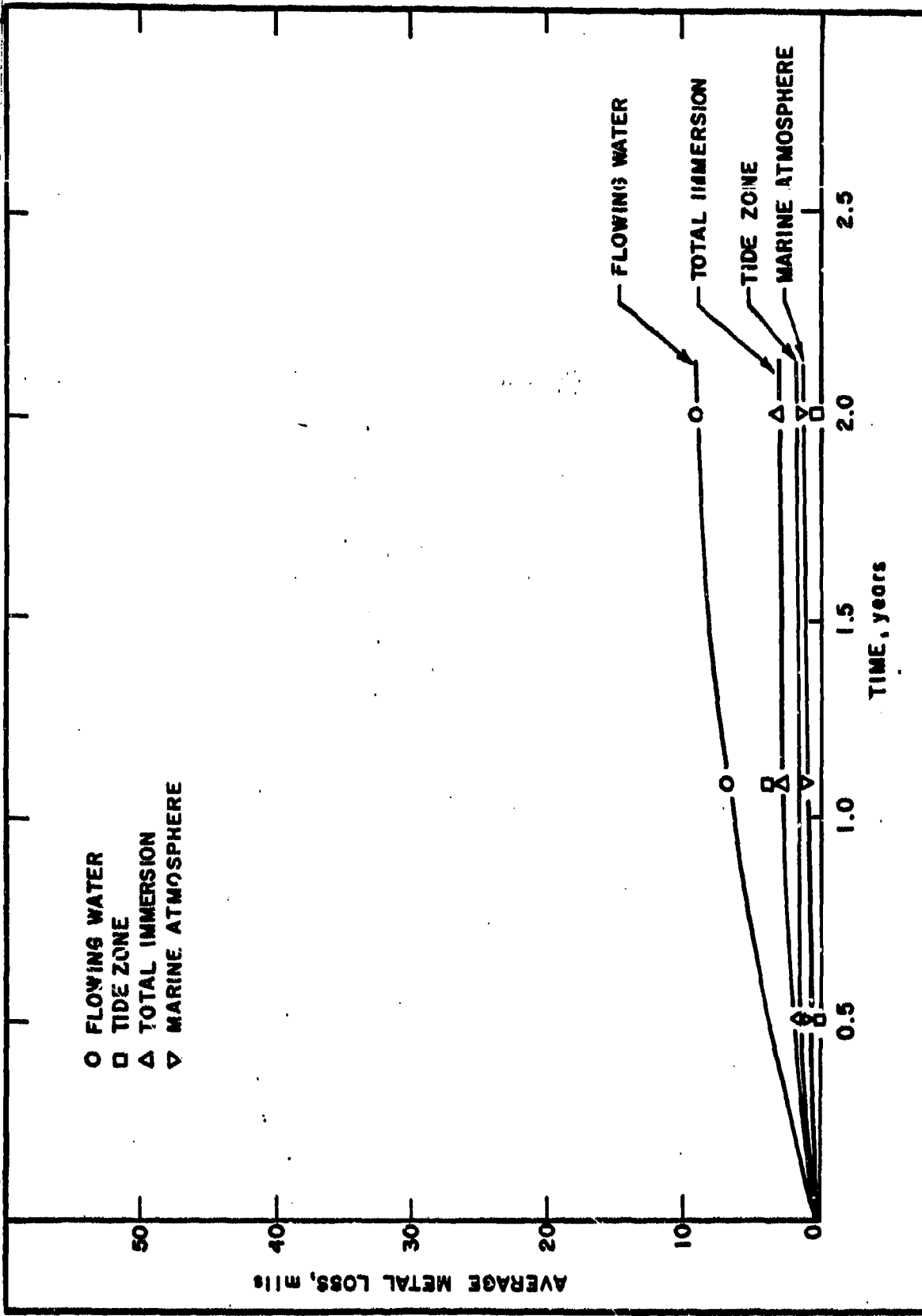
O FLOWING WATER  
 □ TIDE ZONE  
 Δ TOTAL IMMERSION  
 ▽ MARINE ATMOSPHERE

AVERAGE METAL LOSS, mils



BASE-METAL CORROSION OF HY-130(T) STEEL WELDMENTS IN MARINE ENVIRONMENTS

DRAWN BY CHK'D BY G. A. Z. A. W. L.		APPROVED BY E. H. P.		UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.	FIGURE NO. 9
DRAWING NO ARL 1-1449		PROJECT NO 39.001-100 (2)			
		DATE 6-12-67			



HEAT-EFFECTED-ZONE CORROSION OF HY-130 (T) STEEL WELDMENTS IN MARINE ENVIRONMENTS

DRAWN BY: CHK'D BY: S.A.Z. A.W.L.		APPROVED BY: E.H.P.		FIGURE NO. 10
DRAWING NO. ARL 1-1450		PROJECT NO. 39.001-100 (2)		
		DATE 6-12-67		

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O FLOWING WATER  
 □ TIDE ZONE  
 Δ TOTAL IMMERSION  
 ▽ MARINE ATMOSPHERE

AVERAGE METAL LOSS, mils

TIME, years

WELD-METAL CORROSION OF HY-130 (T) STEEL WELDMENTS IN MARINE ENVIRONMENTS

DRAWN BY G.A.Z. A.W.L.		APPROVED BY E.H.P.		FIGURE NO. 11
DRAWING NO. ARL 1-1451		PROJECT NO. 39.001-100(2) DATE 6-12-67		
UNITED STATES STEEL CORPORATION APPLIED RESEARCH PITTSBURGH, PA.				



Figure 12. Welded U-bend stress-corrosion specimen of HY-130(T) steel which cracked in deep-sea water. Etched in Fry's Reagent. Approximately 7X.

Neg. No. 1M-493-B1

39.001-100(2)

Figure 12

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